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Method and device for determining the soot load of a particulate filter

The present invention relates to the field of the purification of the exhaust gases of an internal combustion engine, for example of a motor vehicle and, more particularly, a method and a device for determining the soot load of a particulate filter.

The presence of a particulate filter in the exhaust line of an internal combustion engine, particularly a diesel engine, serves considerably to decrease the quantity of particulates, dust and other soot emitted into the atmosphere, and thereby to comply with the pollution prevention standards.

During the running of the internal combustion engine, the particulate filter is progressively loaded with unburnt hydrocarbons, the accumulation of which ultimately deteriorates the performance of the filter and of the engine, because it results in an increase in the upstream-downstream differential pressure across the filter and hence in the engine exhaust back-pressure. This makes it necessary to regenerate the filter periodically, an operation which is carried out by the combustion of the particulates in the filter.

This thermal regeneration is preferably carried out only when the filter reaches a certain load which can be determined as a function of the loss of efficiency of the filter, the increase in the differential pressure, or a risk of destruction of the filter by excessive heating during the regeneration by combustion of an excessive quantity of soot particles.

Conventionally, the regeneration operation is initiated after a certain time interval, or distance travelled,

but without taking account of the real load of the filter, which is equivalent to taking account of the worst conditions liable to occur and regenerating the filter frequently.

Methods and devices have therefore been developed to optimize the regeneration operations, using an estimation of the real load of the filter, an estimation of its load particularly determined from the type of upstream-downstream differential pressure across the filter.

Document EP-587146 thus teaches a method for regenerating a particulate filter mounted on an atmospheric or turbocharged engine. According to this document, the filter regeneration is initiated as soon as the filter load exceeds a predetermined value. This load is determined from the differential pressure between the inlet and outlet of the filter, denoted ΔP, using the equation $\Delta P = c.A$,

c = filter load

A = quantity characteristic of the gas flow through the engine,

where A depends on the ratio between the product of the engine speed by the pressure in the intake manifold and by the average temperature between the upstream and the downstream end of the particulate filter, and the product of the temperature in the intake manifold by the pressure upstream of the particulate filter.

It appeared to the Applicant that the quantity selected as characteristic of the gas flow through the engine is not really representative of the gases passing through the particulate filter, particularly in case of exhaust gas recirculation, and that, in consequence, the estimation of the filter load could not be determined accurately.

Moreover, this document EP 587 146 mentions no methodology for acquiring the data necessary for calculating the filter load. In fact, considering the measurement dispersions of the various sensors required, it appears important to adopt a precise procedure to guarantee the reliability of the method selected. It is the object of the present invention to determine the load of a particulate filter more accurately than the known prior art and for various types of internal combustion engine.

The method for determining the soot load, according to the invention, is intended for a particulate filter, of the type used downstream of an internal combustion engine, the filter having to be regenerated periodically by combustion of the soot before reaching an excessive load.

The load c is determined from the upstream/downstream differential pressure ΔP of the particulate filter and from quantity A representative of the gas flow in the engine. The said quantity A is representative only of the flow rate of the gases passing through the particulate filter and is obtained from the mass flow rate of fresh air entering the engine (M_{air}) and from the mass flow rate of fuel (Mc) fed to the engine.

The load can be determined using the flowing formulas:

(I) $\Delta P = cA + b$

(II) $A = (M_{air} + M_c)\ \frac{T}{P} N$

where b is a constant
T = exhaust gas temperature upstream of the filter
P = exhaust gas pressure upstream of the filter
N = engine speed.

The exhaust gas pressure upstream of the filter is given by:

$P = \Delta P + Po$

Po = atmospheric pressure.

One can thus determine the soot load of an internal combustion engine, including an engine equipped with an exhaust gas recirculation system, thanks to the fact that the gases actually entering the particulate filter are taken into account. In fact, at a high exhaust recirculation rate, the flow rate reaching the particulate filter is represented by the incoming air flow rate added to the fuel flow rate. The higher the exhaust gas recirculation rate, the lower the fresh air flow rate and hence the lower the flow rate of gases reaching the particulate filter.

In one embodiment of the invention, the parameter c is compared to a maximum predetermined value c_{max} and a filter regeneration is initiated if the parameter c is higher than the said maximum predetermined value c_{max}. A filter regeneration can be initiated if, in addition, certain exhaust temperature, engine speed and fuel flow rate conditions are satisfied, in order to obtain proper combustion of the soot.

In one embodiment of the invention, the proportionality parameter c is calculated from at least two different measurement points.

Advantageously, each measurement point is selected so as to obtain two values of the differential pressure ΔP, each of the values being measured in a predetermined range of the parameter A, the range being provided without overlap.

In one embodiment of the invention, the time Δt elapsed between the first measurement point and the last measurement point is measured, the time Δt is compared to a maximum limit, and if the time Δt is lower than the maximum limit, the soot load is assumed to have

remained constant from the first to the last measurement point.

The device for determining the soot load, according to the invention, is provided for a particulate filter, of the type used downstream of an internal combustion engine, the filter having to be regenerated periodically by combustion of the soot before reaching an excessive load.

The device comprises means for determining the load (c) from the upstream/downstream deferential pressure ΔP of the particulate filter and from a quantity A representative of the gas flow in the engine, characterized in that the said quantity A is representative only of the flow rate of the gases passing through the particulate filter and in that the said quantity A is obtained from the mass flow rate of fresh air entering the engine M_{air} and from the mass flow rate of fuel Mc fed to the engine.

The device may comprise means for determining the load using the following formulas:

(I) $\Delta P = cA + b$

(II) $A = (M_{air} + M_c)\ \dfrac{T}{P}N$

where b is a constant

T = exhaust gas temperature upstream of the filter

P = exhaust gas pressure upstream of the filter

N = engine speed.

The exhaust gas pressure upstream of the filter is given by:

$P = \Delta P + Po$

Po = atmospheric pressure.

A further subject of the present invention is a motor vehicle comprising a device for determining the soot load of the particulate filter as described above.

An accurate determination of the soot load is thus obtained, so that the regeneration by combustion can be initiated at the proper moment, that is, when the filter reaches the maximum load limit set, and without overestimating the load due to the exhaust gas recirculation, and thereby reducing the frequency of regeneration by combustion and increasing the service life of the particulate filter.

The present invention will be better understood from a study of the detailed description of one embodiment, taken as a non-limiting example and illustrated by the drawings appended hereto, in which:

- Figure 1 is a lay out diagram of a particulate filter and of the elements arranged upstream;
- Figure 2 is a curve showing the variation in the differential pressure as a function of the parameter A; and
- Figure 3 is an operating diagram of a system according to the invention.

As may be seen in Figure 1, an engine 1 provided with an intake manifold 2, an exhaust manifold 3, and an injection system 4, is supplied with air by a compressor 5 upstream of which an air flowmeter 6 is positioned to measure the mass flow rate of incoming air M_{air}. The engine 1 is equipped with an exhaust gas recirculation system in the form of a bypass 7 placed between the exhaust manifold 3 and the intake manifold 2, which serves to introduce, into the intake manifold 2, a fraction of the gases produced by the combustion and present in the exhaust manifold 3. The bypass 7 is controlled by an electronic control unit of the engine, not shown, which can vary the exhaust gas recycle rate as a function of the needs of the engine, in order to reduce the formation of pollutant compounds and particularly of nitrogen oxides.

The exhaust manifold 3 is connected to a turbine 8 which drives the compressor 5. The turbine 8 and the compressor 5 are generally coaxial. They are shown in this diagram separately to facilitate understanding. The turbine 8 is provided with a bypass 9.

A particulate filter 10 is arranged at the outlet of the turbine 8.

The upstream end of the filter 10 has the numeral 10a and the downstream end of the filter 10 has the numeral 10b. The downstream part 10b is connected to other devices such as a muffler, not shown. An upstream temperature sensor 11 is installed on the side of the upstream part 10a.

A sensor 12 for measuring the differential pressure ΔP between the upstream part 10a and the downstream part 10b of the filter 10 is also provided and connected to the said upstream 10a and downstream 10b parts. An electronic computer, not shown, is also provided, receiving data from the air flowmeter 6, the injection system 4 which supplies a good quality relative to the mass flow rate of fuel M_c, the temperature sensor 11, and the differential pressure sensor 12. Obviously, instead of the differential pressure sensor 12, an upstream pressure sensor and a downstream pressure sensor could be provided, and the differential pressure ΔP then calculated.

The computer comprises storage means and computation means for which it processes the abovementioned data to estimate the particulate filter load and initiate the regeneration means (not shown), when the load exceeds a predetermined value.

According to the invention, this estimation of the filter load is given by the formula:

(I) $\Delta P = c.A+B$ where ΔP is the upstream-downstream differential pressure across the particulate filter.

C = filter load

A = volumetric flow rate of gases passing through the filter

b = offset of the differential pressure sensor

where A is defined by

(II)

$$A = (M_{air} + M_c) : \frac{T}{P} N$$

M_c= fuel flow rate

T = exhaust gas temperature upstream of the filter

P = exhaust gas pressure upstream of the filter.

In the case in which an upstream pressure sensor is not present, the following is used:

(III) $P = \Delta P + Po$

where Po is the atmospheric pressure considered as being the pressure downstream of the particulate filter.

The load of the particulate filter being determined only from the flow rate of gases passing through the filter and not from the flow rate of gases passing through the engine, a very accurate value of this load is obtained, irrespective of the exhaust gas recirculation rate. Obviously, this determination can also be made for an engine without an exhaust gas recirculation system and/or dP = e atmospheric type.

The filter load being given by the formula:

(I) $\Delta P = cA + B$

It is therefore clear that two measurement points (ΔP_1, and A_1) (ΔP_2, A_2), indeed a single one, may suffice, to obtain c, if b is predetermined. To increase the

accuracy in c, a larger number of measurements can also be taken and c can be obtained by linear regression. According to the invention, the load is determined from at least two measurement points corresponding to substantially different values of A. It may be observed that irrespective of the number of measurement points selected, these measurement points must be sufficiently close together in time to clearly correspond to the same load. In fact, the filter load increases steadily while the engine is running.

Figure 2 shows three measurement points 13, 14 and 15, plotted in a coordinate system having two axes, with the parameter A on the x axis and the differential pressure ΔP on the y axis. Each of the points 13 to 15 has been taken in a range of variation of the parameter A that is limited by the values 16 to 19. Separate ranges can obviously be provided. However, it is important to avoid selecting ranges that intersect, which would make it difficult to plot a straight line most closely approaching the points 13 to 15. We can therefore infer that the first-order equation: $\Delta P = c.A+b$, where b is representative of a shift at the origin and c is representative of the soot load of the particulate filter.

The straight line 20 which can be plotted from the points 13 to 15 is placed below a limit line 21 representative of the permissible limit load of the particulate filter. As long as the line 20 remains below the line 21, the filter is able to operate without regeneration. On the contrary, if the three measurement points define a line, for example, the line 22 placed above the theoretical line 21, the particulate filter would be excessively loaded and its regeneration would be initiated.

The steps of the method for determining the soot load of the particulate filter are shown in Figure 3. The

vehicle is started at step 23. Acquisition of the parameter A takes place in step 24. In step 25, it is confirmed that this acquisition has taken place in the first measurement zone, that is, between the values 16 and 17 in Figure 2. If not, the procedure passes to step 26 in which it is checked that this acquisition has been carried out in the second measurement zone, that is between the values 17 and 18 in Figure 2. If not, the procedure passes to step 27, where the same verification is made for the third measurement zone, that is between the values 18 and 19 in Figure 2. If not, the procedure returns to step 24 of acquisition of the parameter A.

If one of the steps 25, 26 or 27 has permitted acquisition in one of the three zones, the current values of the differential ΔP or of the parameter A are saved and the procedure goes on to step 28. In step 28, the procedure checks if three acquisitions have been made in three different zones during a period Δt shorter than the maximum limit and if the parameter c, which is the slope of the line 20 in Figure 2, is higher than a predetermined value c_{max}. If one of these two conditions is not satisfied, the procedure returns to step 24 of acquisition of the parameter A. If these two conditions are satisfied, a regeneration is initiated by combustion of the soot trapped in the particulate filter (step 29).

Thanks to the invention, the load of the particulate filter is accurately determined, making it possible to space the regenerations without the risk of an excessive filter load causing deterioration of engine performance and excessive heat release during the combustion of the soot, which is liable to damage the filter.

CLAIMS

1. Method for determining the soot load of a particulate filter, of the type used downstream of an internal combustion engine, the filter having to be regenerated periodically by combustion of the soot before reaching an excessive load, whereby the load (c) is determined from the upstream-downstream differential pressure ΔP of the particulate filter and from a quantity A representative of the gas flow in the engine, characterized in that the said quantity A is representative only of the flow rate of the gases passing through the particulate filter and in that the said quantity A is obtained from the mass flow rate of fresh air entering the engine (M_{air}) and from the mass flow rate of fuel (Mc) fed to the engine.

2. Method according to Claim 1, characterized in that the load is determined using the following formulas:

(I) $\Delta P = cA + b$

(II) $A = (M_{air} + M_c)\ \frac{T}{P}N$

where b is a constant

T = exhaust gas temperature upstream of the filter

P = exhaust gas pressure upstream of the filter

N = engine speed.

3. Method according to Claim 2, characterized in that the exhaust gas pressure upstream of the filter is given by:

$P = \Delta P + Po$

Po = atmospheric pressure.

4. Method according to any one of the preceding claims in which the parameter c is compared to a maximum predetermined value c_{max} and a filter

regeneration is initiated if the parameter c is higher than the said maximum predetermined value c_{max}.

5. Method according to Claim 4, in which a filter regeneration is initiated if, in addition, certain exhaust temperature, engine speed and fuel flow conditions are satisfied.

6. Method according to any one of the preceding claims, in which the proportionality parameter c is calculated from at least two different measurement points.

7. Method according to Claim 6, in which each measurement point is selected so as to obtain two values of the differential pressure ΔP, each of the values being measured in a predetermined range of the parameter A, the ranges being provided without overlap.

8. Method according to Claim 7, in which the time Δt elapsed between the first measurement point and the last measurement point is measured, the time Δt is compared to a maximum limit, and if the time Δt is lower than the maximum limit, the soot load is assumed to have remained constant from the first to the last measurement point.

9. Device for determining soot load of a particulate filter, of the type used downstream of an internal combustion engine, the filter having to be regenerated periodically by combustion of the soot before reaching an excessive load comprising means for determining the load (c) from the upstream/downstream deferential pressure ΔP of the particulate filter and from a quantity A representative of the gas flow in the engine, characterized in that the said quantity A is representative only of the flow rate of the gases passing through the particulate filter and in that the said quantity A is obtained from the mass flow rate of

fresh air entering the engine (M_{air}) and from the mass flow rate of fuel (Mc) fed to the engine.

10. Device according to Claim 9, characterized in that it comprises means for determining the load using the following formulas:

(I) $\Delta P = cA + b$

(II) $A = (M_{air} + M_c)\ \frac{T}{P} N$

where b is a constant

T = exhaust gas temperature upstream of the filter

P = exhaust gas pressure upstream of the filter

N = engine speed.

11. Device according to Claim 10, characterized in that the exhaust gas pressure upstream of the filter is given by:

$P = \Delta P + Po$

Po = atmospheric pressure.

12. Vehicle comprising a device according to one of Claims 9 to 11.